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POLYMERIZED LIGHTWEIGHT STRUCTURAL ELEMENTS

ARMY CONSTRUCTION ENGINEERING RESEARCH LABORATORY

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by

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ABSTRACT

Impregnation of concrete materials with polymers was extended to include the impregnation of lightweight foam concretes. Filling approximately 90 percent of the extensive void system of the foam concrete with a polymer increased the compressive strength from 202psi to 3250 psi, the splitting tensile strength from 30psi to 1008psi, and the modulus of elasticity from 100,000psi to 425,000psi. Beam structural elements were partially impregnated to produce a "sandwich panel" element which can utilize the foam concrete core to act as an insulator and as a spacer to separate the polymer impregnated surface regions; and can utilize the polymer impregnated surface regions to resist loadings. The sandwich element produced thus utilizes materials efficiently to satisfy the multiple functional requirements of load and of environment.

FOREWORD

This paper was presented at the Conference on Radiation and Isotope Techniques in Civil Engineering, Brussels, Belgium, October 28 - 30, 1970. The investigation was conducted by the Materials Division of the Construction Engineering Research Laboratory (CERL) in Champaign, Illinois as part of an In-House Laboratory Independent Research project.

CERL personnel directly concerned with this study were Dr. J. L. Lott and D. Birkimer. The Director of CERL is COL R. W. Reisacher and the Chief of Materials Division is Mr. E. A. Lotz.

POLYMERIZED LIGHTWEIGHT STRUCTURAL ELEMENTS

1. Introduction

Polymer impregnated foam concrete is a logical extension of the current research on polymer impregnated concretes.* The relatively high permeability of lightweight foam concrete results in simple preparation techniques for liquid monomer or resin impregnation. Filling the foam voids with a polymer results in significant increases in strength and elastic modulus. Polymer loadings are high because of the large volume of voids in lightweight foam concrete.

Partly polymer impregnated foam concrete structural elements are a practical application because material with high polymer loading can be restricted to surfaces, which have high stresses and act as an interface with environment. The foam concrete core acts as an insulator and as a spacer for the polymer impregnated surface regions. Thus the partly impregnated foam concrete element or "sandwich" panel can satisfy the multiple functional requirements of load and of environment.

Impregnation of hardened portland cement concrete of normal weight by a monomer which is subsequently polymerized in situ results in a polymer-concrete composite material with improved engineering properties. (1-3) Strength, elastic modulus, and durability are increased, and the permeability is reduced.

A portion of the voids in hardened concrete is filled with the liquid monomer. In situ polymerization of the monomer introduces a solid, polymer phase into regions of the concrete that formerly had no strength. This polymer phase alters the properties of the concrete through modification of the cement paste matrix and the matrix-aggregate interface. (4, 5)

The void system of hardened concrete is complex and usually consists of gel and capillary pores in the cement paste, entrained air, entrapped air, and microcracks. The gel pores are characteristic of the portland cement hydration product and are estimated to be of the order of 10 to 20A in size. The characteristics of the capillary pores are dependent on the original water-cement ratio and on the degree of hydration. Capillary pores are estimated to be of the order of 5×10^{-5} in. and form a random void system, which is usually interconnected. The other voids present in concrete are usually larger in size than the capillary pores.

Monomer impregnation or loading is probably limited to the capillary and larger voids and is influenced by the free water and air that are present

* The views expressed in this paper are those of the authors and not necessarily those of the Corps of Engineers or the Department of Defense.

in these voids. Maximum monomer loading of normal weight concrete and optimum engineering properties have been obtained through removal of the free water and air from the voids by vacuum or thermal drying and evacuation of the concrete before monomer soaking. Pressure is often used to reduce the impregnation time. In one case the capillary pore volume of the cement paste was increased to accomplish impregnation by capillary adsorption rather than by evacuation. (6) Only monomers with viscosities that approach the viscosity of water have been used successfully to impregnate normal weight concretes.

Foam cements and concretes have a larger volume of entrained air dispersed throughout a matrix of portland cement to produce a lightweight material with good insulating properties. The permeability, which controls the ease of liquid monomer or resin penetration, increases when the foam voids become interconnected because the liquid can flow through the dispersed voids independently of the gel and capillary pores of the cement paste. Uniformly sized spherical voids become interconnected at a foam void fraction of 0.524, which corresponds to a cubic packing of the spheres.

The permeability of foam cements with foam void fractions above 0.6 is such that highly viscous monomers or resins can penetrate the foam cement. The dispersed voids are large enough to prevent capillary absorption of the viscous liquid, and a driving pressure is required for monomer or resin impregnation of the foam cement.

A pilot study of the concept of partly impregnated foam concrete structural elements was conducted at the U.S. Army Construction Engineering Research Laboratory as a part of the In House Independent Research Program. The study was in general limited to combinations of foam neat cements and a promoted polyester resin with MEK peroxide for a catalyst. This limitation was based on the premise that optimum combinations of foam cements and polymers may be determined once the feasibility of the concept has been verified and the important parameters have been identified.

2. Materials and Preparation

Foam cements were obtained by blending a preformed foam slather into a fresh Type III, high early strength, cement paste with a 0.56 water-cement ratio in a drum mixer for 15 minutes. All specimens were cast without compactive effort and were moist cured for at least three days. Additional curing varied from continued moist curing to air drying.

Two inch cubes and 3 by 6 in. cylinders were used to determine the properties of foam cements and polymer impregnated foam cements. Resin impregnation techniques were developed using 3 by 12 by 22 in. foam cement slabs. A 6 by 6 by 64 in. beam was cast for use in the evaluation of the behavior of a partly impregnated foam cement structural element.

All specimens that were polymerized were impregnated with a promoted 60 percent polyester-40 percent styrene resin, which had a viscosity of approximately 700 cps at room temperature. Resin cure was accomplished at room temperature using 0.5 percent MEK peroxide as a catalyst, and the gel time was about 90 minutes.

Impregnation of the 12 by 22 in. slab surfaces was accomplished by ponding the resin and catalyst within a dike around the top surface. A latent film of cement paste, which tended to form on finished surfaces and closed the dispersed foam voids to resin impregnation, had to be removed by rubbing with a mason's stone prior to resin ponding. A hydraulic head of approximately five inches was required to drive the viscous resin into the foam cements. Ponding of excess resin on the surface to provide this head was wasteful since several inches of resin remained on the surface and gelled rather than penetrating into the foam cement. Impregnation was successfully accomplished by ponding a predetermined weight of resin and catalyst on the surface. The resin was covered with a thin sheet of polyethylene, and then the sheet was ponded with five inches of water to provide the hydraulic head to drive the resin into the foam cement. A similar procedure was used to impregnate the 6 by 6 by 64 in. beam in two steps of polymerizing one surface and then inverting the beam to polymerize the opposite surface. Cube and cylinder specimens were impregnated by soaking the specimens in a resin and catalyst bath with a five inch head of resin. Specimens were removed from the bath before the resin started to gel. All impregnated specimens were cured in the laboratory environment until tested.

3. Results

The foam cements obtained by mechanically blending a preformed foam into fresh cement paste had a dispersed foam void system of spheres that ranged in size from 3×10^{-3} to 3×10^{-2} in. Permeability of the foam cements as indicated by the resin loadings of Table 1 increased with an increase in the foam void fraction or a decrease in density. The 39pcf (pounds per cubic foot) wet density foam cement gained a weight of resin in excess of its original weight. The 39pcf foam cement with this high permeability was used in the development of impregnation techniques.

The viscous resin under a five inch hydraulic head penetrated into the 39pcf foam cement about 0.4 in. in 15 minutes and one inch in one hour. Partial impregnations to depths of one inch and greater were repeatedly obtained in the 39pcf foam cements before the resin gelled. Penetration depths expressed in inches of approximately 0.3 times the weight of resin in pounds per square foot of slab surface were obtained. This corresponds approximately to a 90 percent resin loading of the foam voids.

Resin penetration was uniform away from the edges of the slabs where the penetration was reduced. These edge effects were significant in the 6 by 6 by 64 in. beam and influenced the beam strength.

Drying of the foam cements before impregnation was originally considered necessary because the presence of free water resisted monomer impregnation of normal weight concretes. However, it was found that moisture in the cement paste did not retard resin penetration into the 39pcf foam cement because the highly viscous resin only flowed through the dispersed foam voids, which do not normally fill with water. The presence of moisture in the paste did affect the resin cure, and erratic strengths resulted unless the specimens were air dried for 24 hours.

Strength data, which are the average of three tests, and elastic moduli of foam cements and of resin impregnated foam cements are given in Table 1. All strength specimens were air dried to a constant weight, and then half of the specimens were impregnated with resin and half were used as control specimens.

The 39pcf foam cement had a resin loading of 42pcf, and the compressive strength of the two inch cubes increased from 202psi for the control to 3,250psi for the impregnated foam cement, increasing the compressive strength 15 times. The resin loading and compressive strength increases for the 46pcf and 56pcf foam cements were relatively low because the resistance of these foam cements to resin flow prevented maximum resin loading.

The indirect tensile strength of a 39pcf foam mortar was obtained from the split cylinder test using 3 by 6 in. cylinders. The tensile strength of the foam mortar was 30psi, and the tensile strength of the resin impregnated foam mortar was 1008psi. Filling the dispersed foam voids with resin resulted in a tensile strength increase of 32 times. The fracture surface of the split cylinders contained a large number of fractures through the cured polyester resin. This indicates that sufficient bond developed between the resin and the cement paste for the resin to be effective in tension.

The stress-strain curve was obtained for the 39pcf foam cement using electrical resistance strain gauges on 3 by 6 in. cylinders. The modulus of elasticity of the 39pcf foam cement was 100,000psi. The stress-strain curve for resin impregnated 39pcf foam cement was obtained using a 0.7 by 1.0 by 10.0 in. prism that was cut from the resin impregnated surface region of a 3 by 12 by 22 in. slab. The impregnated foam cement had an elastic modulus of 425,000psi.

The 6 by 6 by 64 in. beam had the tension and compression surfaces impregnated to depths of 0.44 and 0.38 in. respectively. The beam was first subjected to a concentrated load at the centerline of a 60 in. span. The beam failed at a load of 330 pounds and a midspan deflection of 0.07 in. The failure occurred at a cross-section that contained a flaw that was the result of the edge effects associated with impregnation. The longer remaining part of the beam was tested a second time on a span of 33 in. Failure occurred at a centerline load of 880 pounds.

The modular ratio of the impregnated foam cement to the foam cement was 4.25, and calculated shear deformations in the foam cement core or web were negligibly small relative to flexural deformations. The transformed section analysis of reinforced concrete straightline theory was used to evaluate the flexural stress and midspan deflection. Transformation of the 6 by 6 in. cross-section to an elastic modulus of 425,000psi gave a moment of inertia of 54 in.⁴ for an uncracked section and 42 in.⁴ for a section with the foam cement of the core or web carrying no tension. The extreme fiber stress for the 33 in. span beam test was 600psi based on the section carrying no tension in the core. The measured midspan deflection of 0.07 inches is within the calculated deflection range of 0.064 in. and 0.081 in. for the uncracked section and the section that carries no tension in the core respectively.

4. Discussion

Partly impregnated foam cement "sandwich" panels may be fabricated using simple preparation techniques. The combination of 39pcf foam cement and viscous polyester resin results in preparations that do not require thermal drying or evacuation of the foam cement. The simple impregnation procedures are removal of latent paste film from surface; ponding predetermined weight of resin and catalyst on diked surface; covering resin with polyethylene sheet; ponding five inches of water on the polyethylene to drive the resin into the foam cement; leaving the polyethylene sheet on the impregnated surface until the resin is cured to prevent evaporation; and removal of polyethylene from panel.

Drying of foam cement is not required to obtain partly impregnated panels. However, air drying is required to remove moisture, which retards the curing of the polyester-styrene resin.

The polymer-foam cement composite that results from impregnating a 39pcf foam cement with 42pcf of promoted polyester-styrene resin and catalyst has several desirable engineering properties. The density of the composite is only 74pcf. The compressive and indirect tensile strengths are 3,250psi and 1008psi respectively. The compressive to tensile strength ratio is 3.25, which is low relative to both normal concretes and polymer impregnated normal concretes. The elastic modulus is 425,000psi. This low modulus combined with the high tensile strength suggests a high cracking strain for resin impregnated foam cements. The use of such a material with steel reinforcement would allow steel stresses to approach yield before cracking occurs in the polymer impregnated foam cement.

The modular ratio of resin impregnated foam cement to foam cement of the core is only 4.25, which results in small shear deflections in the web of partly impregnated foam cement structural elements. The transformed section analysis of reinforced concrete straight-line theory appears to be applicable to the "sandwich" panels for calculation of stress and deformation.

Table 1

Properties of Foam Cements and Resin Impregnated Foam Cements

Wet Density	Dry Density	Foam Void Fraction	Resin Loading	Compressive Strength	Tensile Strength	Elastic Modulus
pcf	pcf	-	pcf	psi	psi	psi
30	32	0.65	No	202	30*	100,000
Impregnated	74	-	42	3,250	1,008*	425,000
46	41	0.60	No	355	-	-
Impregnated	69	-	28	1,430	-	-
56	49	0.50	No	657	-	-
Impregnated	54	-	4	795	-	-

*39pcf wet density foam mortar specimens were used for indirect tensile strength tests.

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